UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 2005/2006

April/Mei 2006

# IEK 205 – Teknologi Kawalan Pencemaran Udara

Masa: 3 jam

Sila pastikan bahawa kertas peperiksaan ini mengandungi LIMA BELAS mukasurat yang bercetak sebelum anda memulakan peperiksaan ini.

Jawab **EMPAT** soalan. Semua soalan mesti dijawab dalam Bahasa Malaysia.

1. (a) **Terbitkan** persamaan untuk **halaju tamatan** suatu partikel, diameter d, yang mendak dalam udara menurut hukum Stoke.

(20 markah)

(b) **Terbitkan** suatu persamaan untuk kecekapan pemendak graviti (*gravity settlers*) bagi aliran laminar (blok) kemudian **jelaskan dengan ringkas** apa yang perlu dibuat untuk meningkatkan kecekapan sesebuah pemendak graviti.

(20 markah)

(c) **Terbitkan persamaan kecekapan siklon** kemudian **tunjukkan** bagaimana kamu boleh mengira **garis pusat potongan,** $d_{cut}$ (*cut diameter*).

(20 markah)

(d) Suatu siklon beroperasi pada keadaan garis pusat potongan, $d_{cut} = 12\ \mu$. Terdapat cadangan siklon yang rekabentuknya sama tetapi dimensinya separuh dari siklon sekarang. Jika kadar aliran isipadu, beban partikel dan taburan saiz partikel dikekalkan maka **kira nilai $d_{cut}$ yang baru.**

(20 markah)

(e) Tulis nota ringkas mengenai ESP (Electrostatic Precipitator)

(20 markah)

2. (a) Beri gambaran kewujudan pencemar udara utama seperti CO, NOx, SOx, Pb, $O_3$ dan bahan partikulat (abu dan HC yang tak terbakar) melalui suatu contoh proses pembakaran yang mudah.

(60 markah)

(b) Suatu *High Volume Sampler* untuk PM10 dijalankan selama 24 jam pada halaju purata 15 L/min. Berat awal kertas turas ialah 0.1500 g dan berat akhir selepas dikeringkan ialah 0.1505 g. Apakah nilai purata PM10 di udara.

(20 markah)

(c) Kira kepekatan $SO_2$ di sebuah kawasan berhampiran sebuah kilang dalam unit **ppm** jika bacaan kepekatan $SO_2$ ialah 390 $\mu g/m^3$ pada suhu 25 °C dan tekanan 1 atm.

(20 markah)

Maklumat Tambahan

Berat Molekul $SO_2$ = 64, Berat Atom S = 32, O = 16, C = 12

Untuk menukar antara unit ppm dengan $mg/m^3$ guna persamaan berikut:

$$mg/m^3 = \frac{\text{ppm x berat molekul}}{22.414} \times \frac{273.15\ K}{T\ (K)} \times \frac{P\ (atm)}{1\ atm}$$

3. (a) Bermula dengan mengira jumlah jisim habuk yang terpindah ke satu titisan air yang jatuh semasa hujan, dalam persekitaran yang kepekatan habuk ialah c $kg/m^3$ maka **terbitkan suatu persamaan reka bentuk untuk satu *scrubber* aliran silang (*crossflow scrubber*)** yang menerangkan faktor-faktor yang mempengaruhi **ln p**.

p ialah ketembusan ($p = C/C_o$)
C = kepekatan partikel keluar dari *scrubber*
$C_o$ = kepekatan partikel masuk ke *scrubber*

(50 markah)

(b) Keberkesanan *scrubber* ialah 90 peratus bagi partikel saiz 3 μ untuk titisan air bergaris pusat 400 μ. Katakan suatu muncung sembur air diubahsuai supaya titisan air menjadi 200 μ sementara kadar aliran air tidak diubah maka **kira keberkesanan** baru *scrubber* itu.

Diberi $N_s = \rho D^2 V/(18\ \mu D_b)$

$N_s$ = nombor pemisahan
$\rho$ = ketumpatan partikel (2000 $kg/m^3$)
D = diameter partikel
V = halaju tamatan titisan air (*terminal velocity*)
$\mu$ = kelikatan udara ( $1.8 \times 10^{-5}$ kg/ms)
$D_b$ = diameter titisan air (*diameter of barrier*)

(Lihat **Lampiran 1 dan 2** untuk maklumat tambahan)

(50 markah)

4. (a) Satu unit turus padatan (packed tower) digunakan untuk menyerap ammonia dari suatu aliran gas sisa. Unit itu beroperasi pada 70 % halaju banjir jisim gas sisa. Kadar aliran cecair sebenar ialah 30 % lebih daripada takat minimum. Ammonia yang dibenarkan terlepas ialah 10 % daripada yang masuk ke dalam sistem. Cecair pelarut yang digunakan ialah air tulen. Kira tinggi dan diameter menara jika diberi maklumat berikut:

| | |
|---|---|
| Kadar aliran gas | = 6000 lb/h |
| Kepekatan masuk ammonia | = 2.0 mol % |
| Padatan | = 1 in cecincin Raschig (ceramics) |
| $H_{OG}$ | = 2.55 ft |
| Pemalar Henry, m | = 1.25 |
| Ketumpatan gas | = 0.075 $lb/ft^3$ |
| Ketumpatan air | = 62.4 $lb/ft^3$ |
| Kelikatan air | = 1.8 cP |

Berat molekul gas sisa $M_G$ dan air $M_L$ masing-masing ialah 29 dan 18

Diberi:

$Z = N_{OG}.H_{OG}$ ( Z, tinggi menara)

$N_{OG} = 1/(1-\lambda) \ln \left[ (1-\lambda) y_1/y_2 + \lambda \right]$

$y_1$ dan $y_2$ masing-masing ialah komposisi ammonia menurut pecahan mol dalam gas masuk dan gas keluar

$\lambda = mG_m/L_m$

dan masing-masing ialah kadar aliran molar gas dan cecair

$D_T = 1.13\ S^{0.5}$

$D_T$ = diameter menara

S = luas keratan rentas menara

Sila rujuk **Lampiran 3 dan 4** untuk maklumat yang berkaitan.

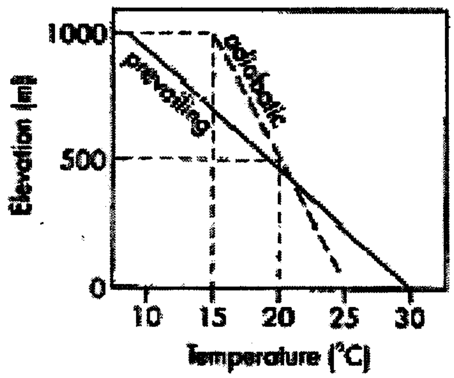
(50 markah)

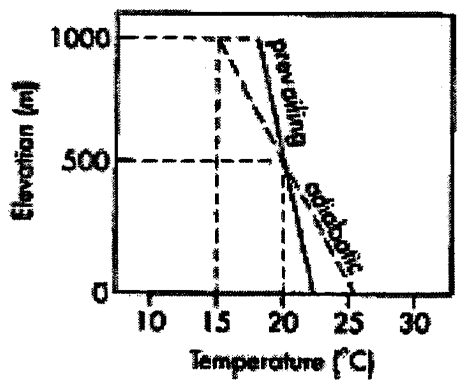
(b) Jelaskan mengenai perawatan gas sisa melalui sama ada kaedah **Penjerapan** atau **Pembakaran.**

(50 markah)

5. (a) Untuk RAJAH 5A dan 5B berikut, apakah yang akan berlaku terhadap asap yang dilepaskan melalui cerobong, tinggi 500 m. Asap keluar dari cerobong pada suhu 20 °C. Beri penjelasan anda melalui pengiraan dan lakaran yang sesuai.

RAJAH 5A. Keadaan sekitaran superadiabatik




RAJAH 5B. Keadaan sekitaran Subadiabatik

(30 markah)

(b) Tulis nota ringkas mengenai perkara berikut:

(i) Songsangan sinaran
(ii) Ketinggian pencampuran
(iii) Ppm
(iv) Garis pusat aerodinamik

(40 markah)

(c) Terdapat cerobong setinggi 150 m di sebuah kilang. Kenaikan plum ialah 75 m. Kilang ini mengeluarkan $SO_2$ pada kadar 1000 g/s. Anggarkan kepekatan aras bumi $SO_2$ daripada punca ini pada jarak 3 km bawah angin (downwind) apabila kelajuan angin ialah 3 m/s dan kelas kestabilan atmosfera ialah C.

Diberi :

Persamaan kepekatan plum yang mempunyai imej-cermin:

$$c = \frac{Q}{2\pi u\sigma_y\sigma_z}\exp-0.5\left(\frac{y}{\sigma_y}\right)^2\left[\exp-0.5\left(\frac{z-H}{\sigma_z}\right)^2+\exp-0.5\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$\frac{cu}{Q} = \frac{l}{\pi\sigma y\sigma z}\exp-0.5\left(\frac{H}{\sigma_z}\right)^2 \quad \text{for } z=0,\ y=0$$

Maklumat tambahan terdapat di dalam **Lampiran 5, 6 dan 7.**

(30 markah)

LAMPIRAN /

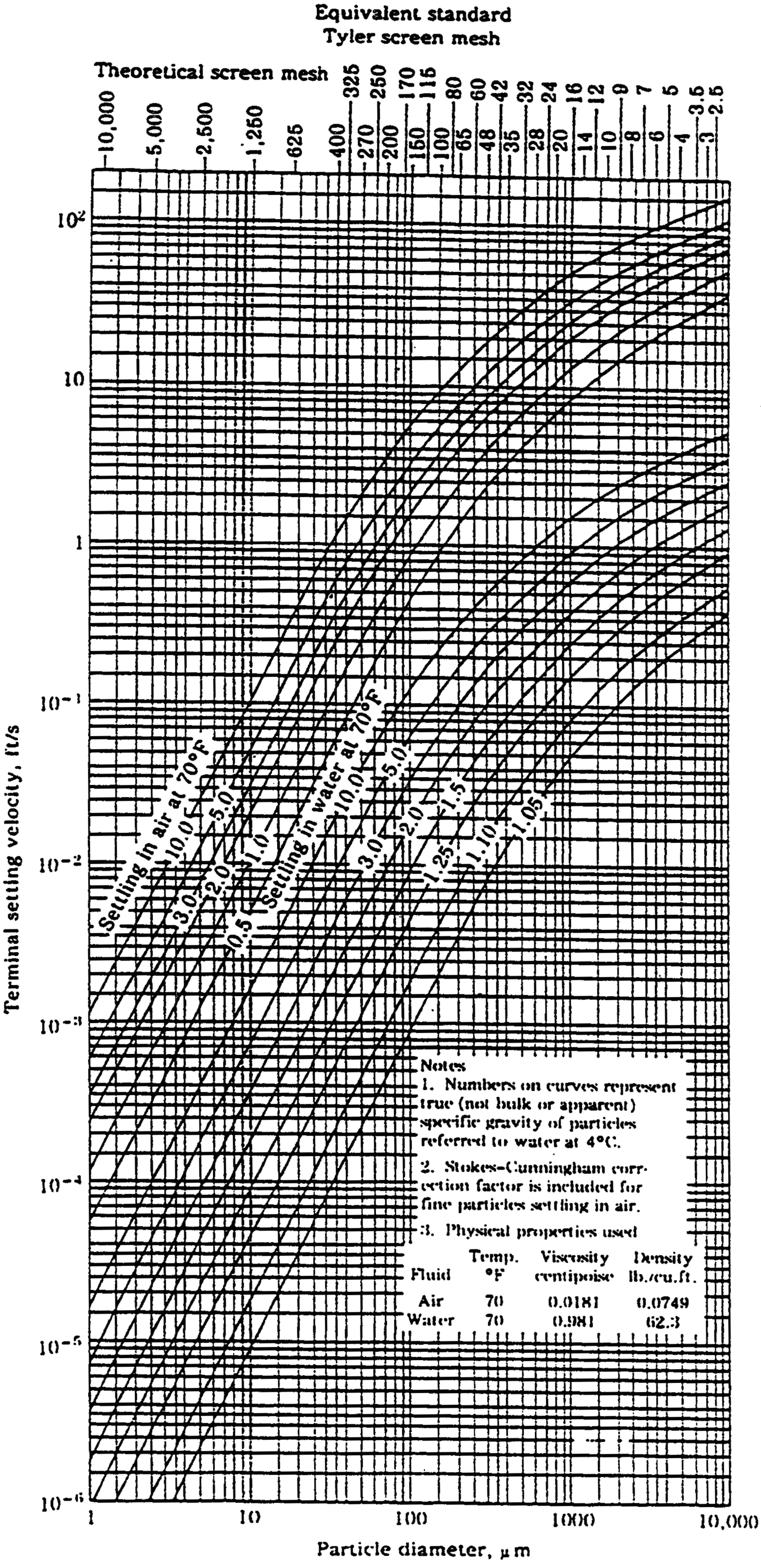



**FIGURE 8.7**

Terminal settling velocities of spherical particles of different densities settling in air and water at 70°F under the influence of gravity. (From C. E. Lapple, et al., *Fluid and Particle Mechanics*, University of Delaware, Newark, 1951, p. 292.) (Observe that the scale is 1, 1.5, 2, 2.5, 3, 3.5, 4, 5....)

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LAMPIRAN 2:

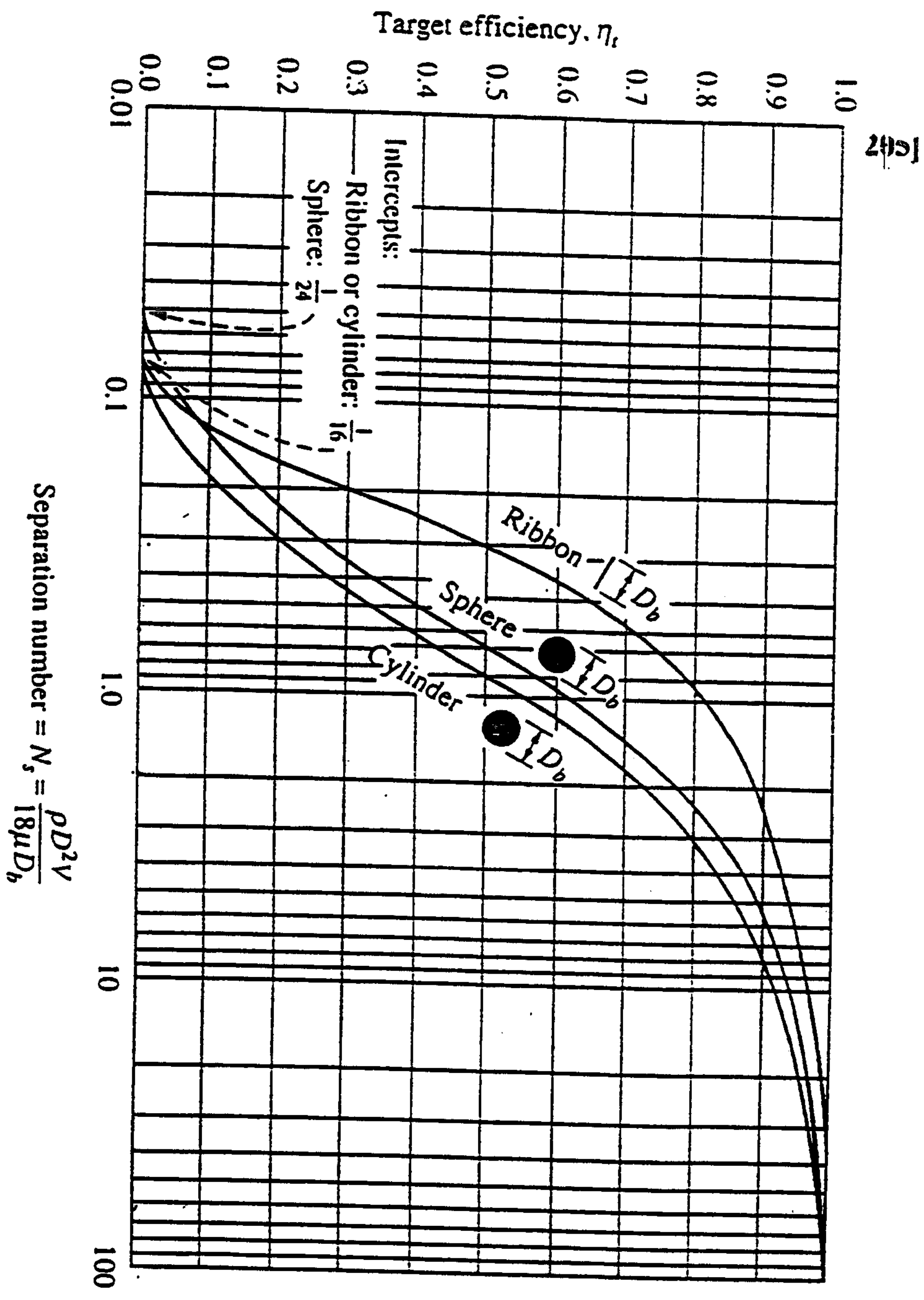


**FIGURE 9.18**
Target efficiency as a function of separation number, for cylinders, ribbons, and spheres. (From Ref. 18.)

LAMPIRAN 3

**TABLE 2. Packing Factors—Dumped Packing**

| | | Nominal Packing Size (inches) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Packing Type | Material | ¼ | ⅜ | ½ | ⅝ | ¾ | 1 | 1¼ | 1½ | 2 | 3 | 3½ |
| Hy-Pak™ | Metal | | | | | | 43 | | | 18 | 15 | |
| Super Intalox® saddles | Ceramic | | | | | | 60 | | | 30 | | |
| Super Intalox saddles | Plastic | | | | | | 33 | | | 21 | 16 | |
| Pall rings | Plastic | | | | 97 | | 52 | | 40 | 25 | | 16 |
| Pall rings | Metal | | | | 70 | | 48 | | 28 | 20 | | 16 |
| Intalox® saddles | Ceramic | 725 | 330 | 200 | | 145 | 98 | | 52 | 40 | 36 | |
| Raschig rings | Ceramic | 1600 | 1000 | 640 | 380 | 255 | 160 | 95 | 65 | 65 | | |
| Raschig rings | $1/32''$ metal | 700 | 390 | 300 | 170 | 185 | 115 | | | | | |
| Raschig rings | $1/16''$ metal | | | 410 | 290 | 230 | 137 | 110 | 83 | 57 | 32 | |
| Berl saddles | Ceramic | 900 | | 240 | | 170 | 110 | | 65 | 45 | | |
| Tri-packs | Plastic | | | | | | 28 | | | 15 | | 14 |
| Tri-packs | Metal | | | | | | | | | 18 | 14 | |

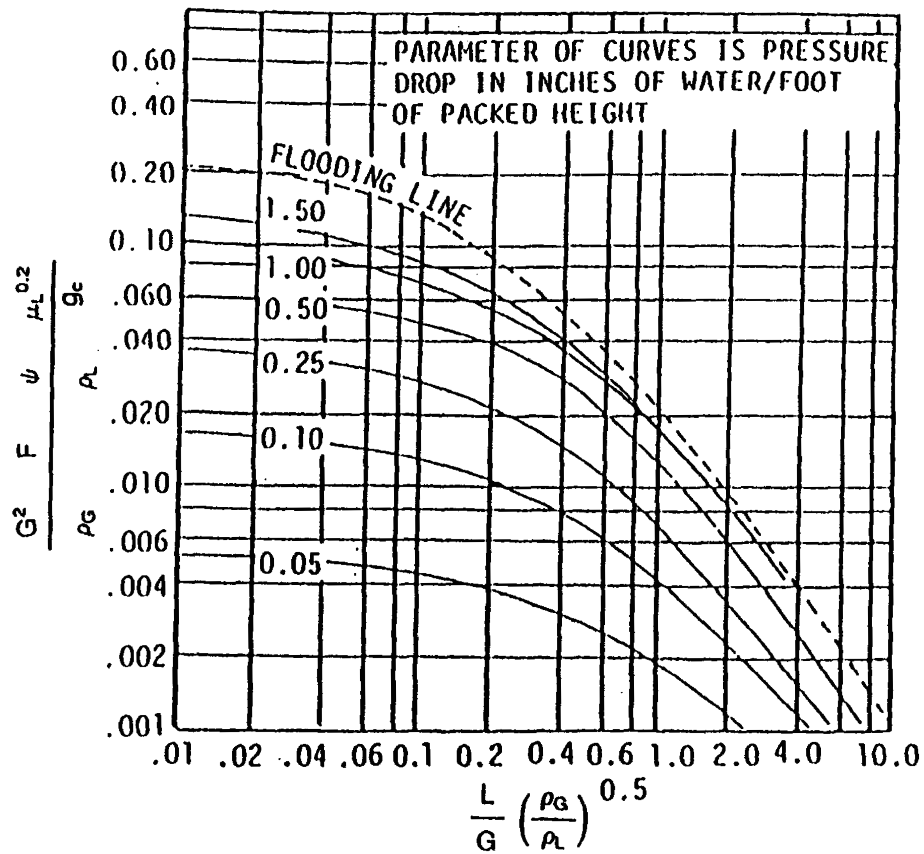


**FIGURE 7.** Generalized Pressure Drop Correlation to Estimate Column Diameter ($G$ = gas flow rate, lb/sec ft$^2$; $L$ = liquid flow rate, lb/sec ft$^2$; $F$ = packing factor; $\Psi$ = ratio, density of water/density of liquid; $\mu_L$ = liquid viscosity, cP$_a$; $\rho_G$ = gas density, lb/ft$^3$; $\rho_L$ = liquid density, lb/ft$^3$; $g_c$ = 32.2).

LAMPIRAN 5

Table 7.7 Wind Profile Exponent $p$, for Rough Terrain[a]

| Stability Class | Description | Exponent $p$ |
|---|---|---|
| A | Very unstable | 0.15 |
| B | Moderately unstable | 0.15 |
| C | Slightly unstable | 0.20 |
| D | Neutral | 0.25 |
| E | Slightly stable | 0.40 |
| F | Stable | 0.60 |

[a] For smooth terrain, multiply $p$ by 0.6; see Table 7.8 for further descriptions of the stability classifications used here (Peterson, 1978).



Table 7.8 Atmospheric Stability Classifications

| Surface wind speed[a] (m/s) | Day solar insolation | | | Night cloudiness[e] | |
|---|---|---|---|---|---|
| | Strong[b] | Moderate[c] | Slight[d] | Cloudy ($\geq 4/8$) | Clear ($\leq 3/8$) |
| < 2 | A | A–B[f] | B | E | F |
| 2–3 | A–B | B | C | E | F |
| 3–5 | B | B–C | C | D | E |
| 5–6 | C | C–D | D | D | D |
| > 6 | C | D | D | D | D |

[a]Surface wind speed is measured at 10 m above the ground.
[b]Corresponds to a clear summer day with sun higher than 60° above the horizon.
[c]Corresponds to a summer day wth a few broken clouds, or a clear day with sun 35–60° above the horizon.
[d]Corresponds to a fall afternoon, or a cloudy summer day, or clear summer day with the sun 15–35° above the horizon.
[e]Cloudiness is defined as the fraction of sky covered by clouds.
[f]For A–B, B–C, or C–D conditions, average the values obtained for each.
*Note:* A, Very unstable; B, moderately unstable; C, slightly unstable; D, neutral; E, slightly stable; F, stable. Regardless of windspeed, class D should be assumed for overcast conditions, day or night.
*Source:* Turner (1970).

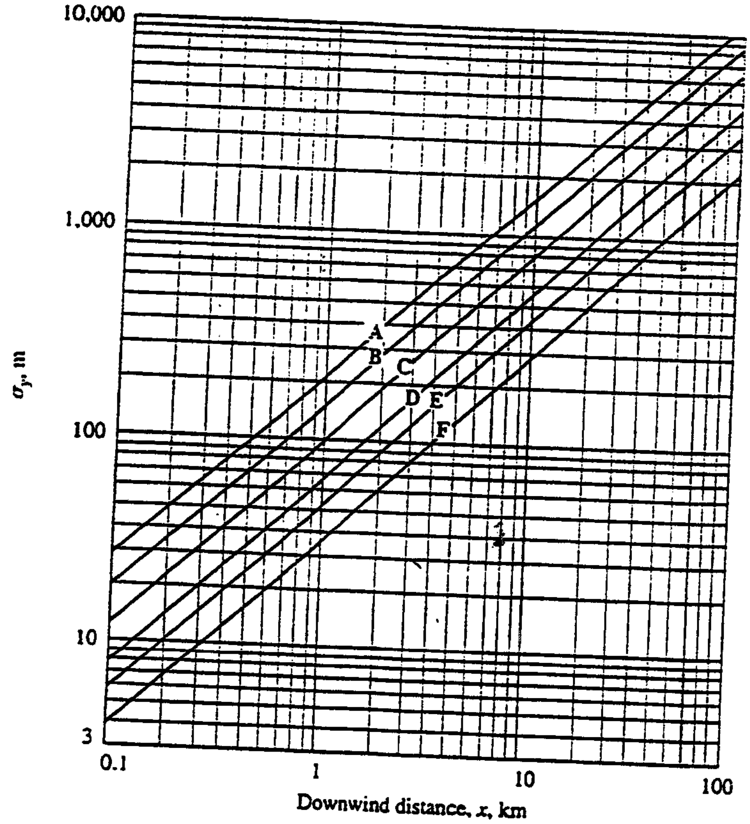


**FIGURE 6.7**
Horizontal dispersion coefficient $\sigma_y$ as a function of downwind distance from the source for various stability categories. See Problem 6.16. (From Turner [7].)

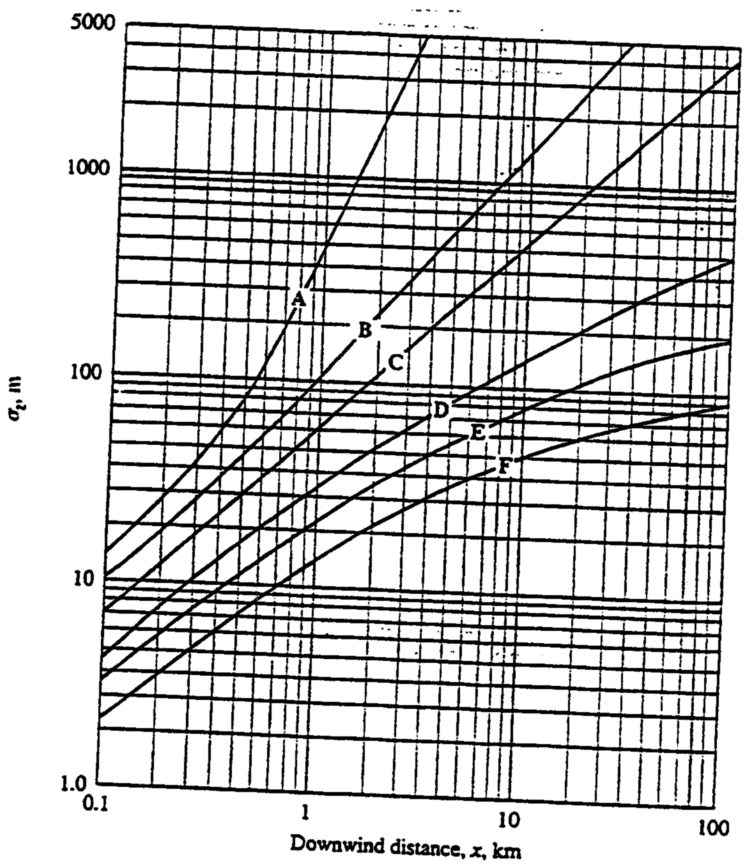


**FIGURE 6.8**
Vertical dispersion coefficient $\sigma_z$ as a function of downwind distance from the source for various stability categories. See Problem 6.16. (From Turner [7].)

LAMPIRAN 7

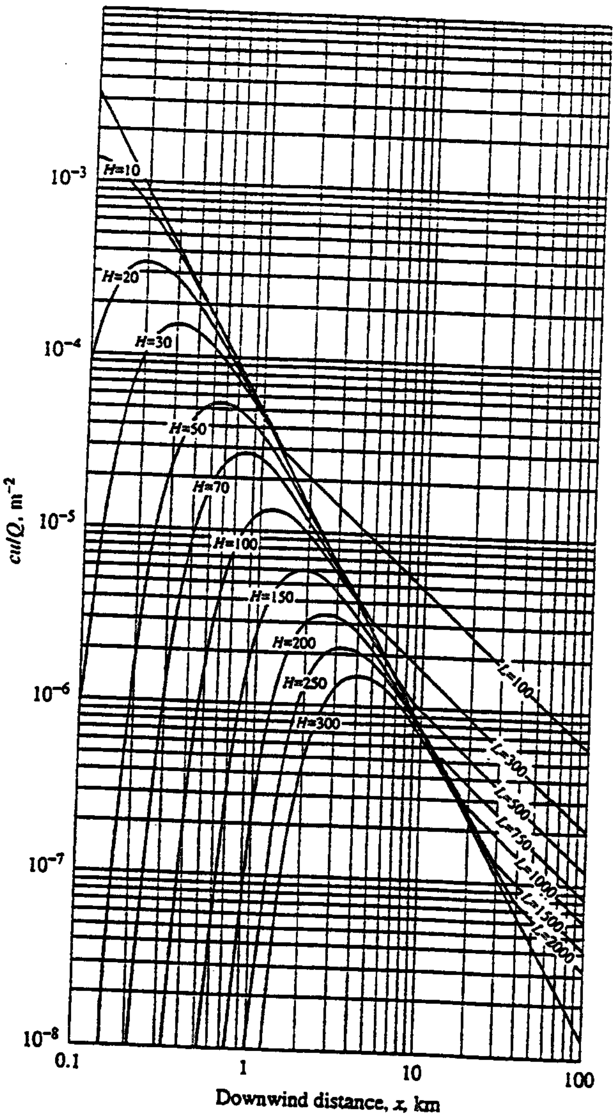


**FIGURE 6.9**
Ground-level $cu/Q$, directly under the plume centerline, as a function of downwind distance from the source and effective stack height, $H$, in meters, *for C stability only.* (From Turner [7].) Here $L$ is the atmospheric mixing height, also in meters.

LAMPIRAN 8

## CONVERSION FACTORS*

**Length:**

$$1 \text{ ft} = 0.3048 \text{ m} = 12 \text{ in.} = \text{mile}/5280 = \text{nautical mile}/6076$$
$$= \text{km}/3281$$
$$1 \text{ m} = 3.281 \text{ ft} = 39.37 \text{ in.} = \text{km}/1000 = 100 \text{ cm} = 1000 \text{ mm}$$
$$= 10^6 \text{ microns} = 10^6\ \mu\text{m} = 10^9 \text{ nm} = 10^{10}\ \text{Å}$$

**Mass:**

$$1 \text{ lbm} = 0.45359 \text{ kg} = \text{short ton}/2000 = \text{long ton}/2240 = 16 \text{ oz (av.)}$$
$$= 14.58 \text{ oz (troy)} = \text{metric ton (tonne)}/2204.63 = 7000 \text{ grains}$$
$$= \text{slug}/32.2$$
$$1 \text{ kg} = 2.2046 \text{ lbm} = 1000 \text{ g} = (\text{metric ton or tonne or Mg})/1000$$

**Force:**

$$1 \text{ lbf} = 4.4482 \text{ N} = 32.2 \text{ lbm} \cdot \text{ft/s}^2 = 32.2 \text{ poundal} = 0.4536 \text{ kgf}$$
$$1 \text{ N} = \text{kg} \cdot \text{m/s}^2 = 10^5 \text{ dyne} = \text{kgf}/9.81 = 0.2248 \text{ lbf}$$

**Volume:**

$$1 \text{ ft}^3 = 0.02831 \text{ m}^3 = 28.31 \text{ liters} = 7.48 \text{ U.S. gallons}$$
$$= 6.23 \text{ Imperial gallons} = \text{acre-ft}/43\,560$$
$$1 \text{ U.S. gallon} = 231 \text{ in.}^3 = \text{barrel (petroleum)}/42 = 4 \text{ U.S. quarts}$$
$$= 8 \text{ U.S. pints} = 3.785 \text{ liters} = 0.003785 \text{ m}^3$$
$$1 \text{ m}^3 = 1000 \text{ liters} = 35.29 \text{ ft}^3$$

**Energy:**

$$1 \text{ Btu} = 1055 \text{ J} = 1.055 \text{ kw} \cdot \text{s} = 2.93 \times 10^{-4} \text{ kwh} = 252 \text{ cal}$$
$$= 777.97 \text{ ft} \cdot \text{lbf} = 3.93 \times 10^{-4} \text{ hp} \cdot \text{h}$$
$$1 \text{ J} = \text{N} \cdot \text{m} = \text{W} \cdot \text{s} = \text{volt} \cdot \text{coulomb} = 9.48 \times 10^{-4} \text{ Btu}$$
$$= 0.239 \text{ cal} = 10^7 \text{ erg} = 6.24 \times 10^{18} \text{ electron volts}$$

*These values are mostly rounded. There are several definitions for some of these quantities, e.g., the Btu and the calorie; these definitions differ from each other by up to 0.2 percent. For the most accurate values see the *ASTM Metric Practice Guide*, ASTM Pub. E 380-93, Philadelphia, 1993.

LAMPIRAN 9

**Power:**

$$1\ \text{hp} = 550\ \text{ft} \cdot \text{lbf/s} = 33\ 000\ \text{ft} \cdot \text{lbf/min} = 2545\ \text{Btu/h} = 0.746\ \text{kW}$$

$$1\ \text{W} = \text{J/s} = \text{N} \cdot \text{m/s} = \text{volt} \cdot \text{ampere} = 1.34 \times 10^{-3}\ \text{hp} = 0.239\ \text{cal/s} = 9.49 \times 10^{-4}\ \text{Btu/s}$$

**Pressure:**

$$1\ \text{atm} = 101.3\ \text{kPa} = 1.013\ \text{bar} = 14.696\ \text{lbf/in.}^2 = 33.89\ \text{ft of water} = 29.92\ \text{inches of mercury} = 1.033\ \text{kgf/cm}^2 = 10.33\ \text{m of water} = 760\ \text{mm of mercury} = 760\ \text{torr}$$

$$1\ \text{psi} = \text{atm}/14.696 = 6.89\ \text{kPa} = 0.0689\ \text{bar} = 27.7\ \text{in. } H_2O = 51.7\ \text{torr}$$

$$1\ \text{Pa} = \text{N/m}^2 = \text{kg/m} \cdot \text{s}^2 = 10^{-5}\ \text{bar} = 1.450 \times 10^{-4}\ \text{lbf/in.}^2 = 0.0075\ \text{torr} = 0.0040\ \text{in. } H_2O$$

$$1\ \text{bar} = 10^5\ \text{Pa} = 0.987\ \text{atm} = 14.5\ \text{psia}$$

**Psia, psig:**

Psia means pounds per square inch, absolute. Psig means pounds per square inch, gauge, i.e., above or below the local atmospheric pressure.

**Viscosity:**

$$1\ \text{cp} = 0.01\ \text{poise} = 0.01\ \text{g/cm} \cdot \text{s} = 0.001\ \text{kg/m} \cdot \text{s} = 0.001\ \text{Pa} \cdot \text{s} = 6.72 \times 10^{-4}\ \text{lbm/ft} \cdot \text{s} = 2.42\ \text{lbm/ft} \cdot \text{h} = 2.09 \times 10^{-5}\ \text{lbf} \cdot \text{s/ft}^2 = 0.01\ \text{dyne} \cdot \text{s/cm}^2$$

**Kinematic viscosity:**

$$1\ \text{cs} = 0.01\ \text{stoke} = 0.01\ \text{cm}^2/\text{s} = 10^{-6}\ \text{m}^2/\text{s} = 1\ \text{cp}/(\text{g/cm}^3) = 1.08 \times 10^{-5}\ \text{ft}^2/\text{s} = \text{cp}/(62.4\ \text{lbm/ft}^3)$$

**Temperature:**

$$K = °C + 273.15 = °R/1.8 \approx °C + 273 \qquad °C = (°F - 32)/1.8$$

$$°R = °F + 459.67 = 1.8\ K \approx °F + 460 \qquad °F = 1.8°C + 32$$

**Concentration (ppm):**

In the air pollution literature and in this book, ppm applied to a gas always means parts per million by volume or by mol. These are identical for an ideal gas, and practically identical for most gases of air pollution interest at 1 atm pressure. Ppm applied to a liquid or solid means parts per million by mass.

For perfect gases at 1 atm and 25°C, 1 ppm = (40.87 · molecular weight) $\mu g/m^3$

**Common Units and Values for Problems and Examples:**

See inside back cover.

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